

1. Science aim/goal (provide a high-level statement in 140 characters or less):
A FIR-Survey of TNOs and Related Outer Solar System Small Bodies

(i) Scientific Importance:

The small solar-system bodies that reside between 30 and 50 AU are referred to as the Trans Neptunian Objects, or TNOs. They comprise, in fact, the majority of small bodies within the solar system and are themselves a collection of dynamically variegated subpopulations, including Centaurs and Scattered-Disk Objects (SDOs), as well as “cold” (low-inclination and eccentricity) and “hot” (high eccentricity) classical Kuiper Belt populations (KBOs; Gladman et al. 2008). These minor planets are the reservoir of the comets that routinely visit our inner solar system, the short period comets, and so cloud the distinction between asteroids and comets. They are primordial material, unmodified by the evolution of the solar system after their emplacement and are the sources of volatile materials to the inner solar system. TNO and outer solar system small body size distributions, down to scales of 10s of km or \sim a few km (Dones et al. 2015, and ref. therein) provide tests of the formation scales of planetesimals and evolutionary models of the early Solar system. The ability to derive large quantities of size measurements is a unique value of such FIR surveys. Small bodies typically can vary in their surface reflectivity by factors of 5 or more, while surveys that detect emitted light provide reliable sizes from the flux (cf. Mainzer et al. 2011). This is important because the previous optical surveys have provided alternate size frequency distributions, based on inferences of reflectivity, indicative of competing evolution histories for these bodies (cf. Dones et al. 2015) especially at the smaller end (TNO diameters <100 km) of the size scales. Objects at TNO distances will be best detected at wavelengths near $110\text{ }\mu\text{m}$. Shorter ($\sim 70\text{ }\mu\text{m}$), and longer ($\sim 200\text{ }\mu\text{m}$), wavelengths will better constrain the sizes and temperatures of the objects observed. Presently, most surveys have placed order-of-magnitude constraints on larger TNOs, with solar-system absolute magnitudes (H) <9 and sizes >100 km. Focused studies of particular objects of interest would also be possible. Study of TNOs, and interlopers into near-TNO distances from even further populations in the Oort cloud, can thus inform us about the early history of the solar system, and how its composition has evolved over the time since it was formed, but while removed from the effects of strong insolation and while the bulk of their volatiles are intact. The thermal radiation of objects from 30 to 100 AU from the Sun, with temperatures $\sim 30\text{--}50\text{ K}$, provide sufficient flux at $\sim 100\text{ }\mu\text{m}$ to probe the most interesting size scales of the outer solar system populations.

(ii) Measurements Required:

The main requirement is to image a large area of the sky multiple times and capture large numbers of TNOs and related outer solar system objects. A single band near $125\text{ }\mu\text{m}$ and with sensitivities $\sim 13\text{--}50\text{ }\mu\text{Jy}$ would reach large numbers (many thousands) and small ($\sim 7\text{--}20$ km; Figure 1) sizes. Other bands, $\sim 70\text{ }\mu\text{m}$ and $250\text{ }\mu\text{m}$, with comparable sensitivities, would provide better temperature, and therefore size, constraints. The survey will have to cover the area several times so motion, ~ 2 arcseconds per hour (mostly parallax from the Earth’s motion), can be detected and confirmed. With coverage of 4 integrations over the course of hours to days, an orbital distance can be constrained, and a repeated observation, a few months later, can establish an orbit for each object. The multiple coverage required to quantify sky motion also mitigates confusion noise.

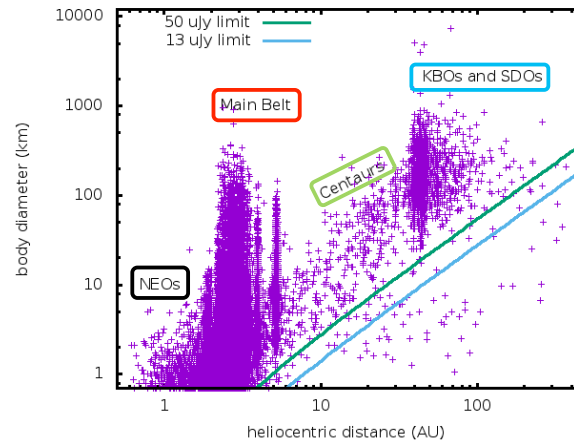
(iii) Uniqueness to 10 μ m to few mm wavelength facility:

Only a FIR imaging survey can reach the sensitivity and the speed that may be able to meet the cadence requirements. A 20m FIRS can reach a 5 sigma sensitivity of $\sim 13 \mu\text{Jy}$ in $\sim 14\text{s}$ of integration, and 4 repeated observations over the course of several days could allow for the coverage of 2000 square degrees of sky in ~ 8000 hours for a 14 square arcmin FOV. For a quarter square degree FOV with a 10m telescope, a similar survey interval would cover roughly 20% of the sky down to sizes of $\sim 20\text{km}$.

(iv) Longevity/Durability: (with respect to expected 2025-2030 facilities)

For bodies with $\sim 10\%$ albedo and 20 km in diameter at 40 AU, the visual brightness is $\sim 27.6 \text{ m}_V$, not detectable by LSST ($< 25 \text{ m}_V$) or other surveys. LSST therefore cannot compete in the characterization of outer solar system small bodies, and owing to the uncertainty in their reflectance, cannot determine their sizes with similar confidence as a thermal survey.

3. Figure: Sensitivity limits of small bodies as observed by a 125 μm imaging survey with a 10, or 20m telescope are ~ 50 and $13 \mu\text{Jy}$ respectively (green, & blue lines). Purple crosses represent objects from the Minor Planet Center database (7/19/16), with sizes assuming 10% albedo in thermal equilibrium with insolation, and are plotted at their semi-major axis values.



4. Table:

Parameter	Unit	Required value	Desired Value	Comments
Wavelength/band	μm	100	70, 100, 200	
Number of targets		>1000		
Survey area	deg.^2	>1000	20,000	
Angular resolution	arcsec	3	2	
Spectral resolution	$\Delta\lambda/\lambda$	0.3	0.3	
Continuum Sensitivity	μJy	50	10	
Spectral line sensitivity	W m^{-2}	NA	NA	
Dynamic range				
Cadence		4 in 8h to 7d	2+ epochs	
Any other requirement	FOV	14X14 arcmin	~ 0.25 to 1.0 sqr degrees	

5. Key references: Dones et al. 2015. Space Sci Rev (2015) 197, 191.; Gladman et al. 2008, in The Solar System Beyond Neptune (Tucson, AZ: Univ. Arizona Press), 43.; Mainzer et al. 2011. NEOWISE Observations of Near-Earth Objects: Preliminary Results. ApJ. 743, 156.